

## **FY99 Basic Research Program**

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### **LONG-TERM GOAL**

The Basic Research Program at ARL:UT emphasizes the Laboratories' commitment to 6.1 research, utilizing the expertise of faculty, research staff, and students in collaborative efforts. Publishing in archival journals and focusing new 6.1 research thrusts in arenas of future naval significance is encouraged, as are transitions to possible future funding under other ONR and DoD programs.

### **FY99 RESEARCH PROJECTS**

**Development of a CIT Constrained Electron Density Model**, Dr. Gary Bust: This project started with the objective of developing an ionospheric tomography algorithm that was constrained by a first principle physics model, the concept being that ionospheric tomography is a limited angle inversion problem which does not have a unique solution without a priori information, and that the least ad hoc a priori information that can be applied is in the form of a fundamental physics equation constraint. It then became obvious that the best way to couple the physics to ionospheric tomography was through data assimilative methods. Thus, the focus of this project has been to develop a fully data assimilative ionospheric tomography method.

Work at this point has been based on that described by Roger Daley. We have developed a statistically minimized tomography inversion algorithm that is based on the data error covariance matrix and the background (or forecast) model error covariance matrix. If both of the error covariances are known exactly, the solution is the optimal linear solution. Basically, the algorithm works as follows: (1) A predictive (or empirical) ionospheric model makes a prediction of the ionospheric state at the time the data was collected. (2) The difference between the predicted data and the measured data is used as the innovation vector. (3) The "objectively analyzed" electron density is obtained by multiplying the inverse matrix, which is obtained from the two error covariance matrices on the innovation vector.

Currently, the algorithm has the following characteristics: (1) It operates on a regional grid, typically some 70 degrees of latitude, 30-50 degrees of longitude, and from 80-1000 km altitude. (2) It accepts beacon dual frequency TEC data, ground GPS TEC data and ionosonde data as input. (3) It uses the empirical models IRI-95 and PIM, as well as the first principle model FLIP as the forecast model. (4) In addition to producing the objectively analyzed electron density field, it also produces the formal error variance in the solution. (5) The output electron density is suitable for re-initialization of basic forecast models and can be input to FLIP.

Future plans include using a continuity equation model developed at ARL:UT as the forecast model, making the algorithm global, and adding satellite EUV data sources, satellite GPS TEC data sources,

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and DMSP in situ electron density measurements. Finally a simple Kalman filter update should be ready in time to take advantage of the time history of the algorithm outputs.

One archival paper is in process, and three presentations were given at conferences.

**Three Dimensional Electromagnetic Propagation Using High Performance Computing,** Thomas N. Lawrence and Dr. Roy M. Jenevein: Existing electromagnetic propagation models are predominantly two dimensional and do not take into account propagation around the sides of obstacles, the terrain gradients transverse to great circle paths, or secondary reflections from environmental features like hills or mountain sides. Information is lost if propagation models do not consider cross-bearing propagation. In mission planning, receivers that were thought to be illuminated might not be, or vice versa, putting a mission and people at risk. Using a Pade' based parabolic equation approach based upon a formulation put forth by Lee, et al. (Ding Lee, et al., An efficient method for solving the three-dimensional wide angle wave equation, Research Report YALEU/DCS/RR-463, October 1986), a basic three dimensional multiprocessor propagation model was developed for execution on the Cray T3E, which has up to 80 user processors. The development was done using the Message Passing Interface (M. Snir, et al., *MPI: The Complete Reference*, MIT Press, Cambridge, MA, 1996) and LAPACK (E. Anderson, et al., *LAPACK Users' Guide*, SIAM, Philadelphia, PA, 1992), which are standard multiprocessor tools. The intention is to create software, which will run on most or all multiprocessor environments with little modification. The details of the modeling approach and how this approach can be applied to current and future multiprocessor computer systems will be discussed. The outlook for multiprocessor technology for Naval related applications will be touched upon.

**Identification of Chemical Composition by Electron Activated Nuclear Gamma Ray Spectroscopy, Robert L. Rogers:** This investigation focused on determining whether it is possible to detect the elemental composition of a material using 100MeV electrons or the bremsstrahlung gamma rays generated by the electrons to excite the low-lying energy states in the nuclei of the material. The observation of the spectra of the "fluorescence" as the nuclei transition back to their ground states provides a spectral signature dependent on the elemental composition. Light elements, such as carbon and nitrogen, have states with well-defined transition energies. Computer models have been used calculate the interaction of the electrons and the bremsstrahlung radiation with the composite materials. GEANT, which is a Monte Carlo code, has been used to perform the calculations. A simple detector model was also used in the simulations to provide an estimate of the observed signal-to-noise ratio. Present results indicate that with detector resolutions of a few hundred eV to 1keV, adequate signal-to-noise ratios can be achieved. Current efforts are focused on improving the signal-to-noise and adding a more detailed detector model to the simulation. This will allow the evaluation of a variety of detector materials to see if they have sufficient resolution to allow elemental composition identification. Possible applications of this technique are the identification of unexploded ordinance, classification and detection of buried landmines and ordinance buried in surf zone areas, and cargo inspection. Others applications include the detection of toxic contamination in soils or unopened containers.

**Non-Linear Methods for Early Crack Detection and Localization, Danny W. Linehan and Ronald O. Stearman:** The vibration response of three beams is being studied for possible non-linear output. Previous numerical studies by several researchers have shown that a cracked beam in transverse vibration will display a strong non-linear response to a harmonic input. Each beam is made of aluminum 6061 alloy and has a cross sectional area of 0.375" x 0.725". The beams are clamped (constrained in all directions and rotations) with an effective length of 44". One beam has no crack, the second has a crack about 10% of the beam height (or about 0.07-0.08"), and the third has a crack about

25% of the beam height (about 0.18"-0.2"). A 5 lb. test shaker excites the beam at its tip, and accelerometers and strain gages are used to record the beam response. Initial narrow band excitation results are promising from the accelerometer data, but the strain gage data is inconclusive. The beam was excited at 50 Hz, 80 Hz, 100 Hz, 125 Hz, and 150 Hz at low amplitude, and power spectrums of the accelerometer data were produced. Generally, the uncracked beam showed little or no response at the second and third harmonic of the excitation frequency. The two cracked beams showed amplified harmonic responses at twice and triple the excitation frequency. These responses were not necessarily greater in the 25% cracked beam. The third harmonic was usually greater than the second for both cracked beams. To summarize the accelerometer data, a general trend of amplified harmonic response to the excitation frequency was observed in the cracked beams. The harmonic response was usually on the order of 40-60 dB lower than the excitation response for the cracked beams and 70-80 dB lower than the excitation response for the uncracked beam. The strain gage data did not add conclusive results to the experiment. The three beams were excited at 50 Hz and 75 Hz at a much higher amplitude. The strain gages were arranged in a half bridge configuration, and the output was amplified and recorded. The power spectrums of these results revealed no patterns of harmonics rising above the noise floor for the cracked beams; the uncracked beam was as likely to have harmonics as the cracked beams. Future work includes quantifying the current results and modal testing of all three beams. In addition, future experiments will begin to focus on random input excitation and the higher-order spectral analysis of the output. Finally, it may be possible to develop a numerical simulation of random excitation so that a numeric solution for the output can be obtained.

**Geoacoustic Inversion Using Shallow Water Acoustic Data, David P. Knobles:** Acoustic data from two shallow water locations, a site in the Gulf of Mexico and a site in the Yellow Sea, are used to estimate geoacoustic representations of the seabed. The Gulf of Mexico site is located in an area where extensive geophysical information is present. An inversion experiment using the SWAMI 52-element horizontal line array was made for this location. The Yellow Sea site is located in a region where several previous acoustic inversions have been made. Simulated annealing in conjunction with a normal mode propagation model is used for both data sets with different combinations of CW and broadband data. The results are in good agreement with existing geophysical data and previous inversions.

### **Papers in preparation**

D. P. Knobles, "A broadband geoacoustic inversion experiment in the Gulf of Mexico," in preparation for Journal of Acoustical Society of Am.

D. P. Knobles and C. S. Penrod, "Extraction of bottom scattering strengths below 1 kHz from inversion of forward problem," in preparation for Journal of Underwater Acoustics.

**Neutralization of Explosives by Plasma Jet Impingement: Feasibility Study,** Dennis E. Wilson, and Dennis Peterson: Preliminary results of an experimental study to determine the feasibility of neutralizing explosives by using a high-temperature, high-velocity pulsed plasma jet are presented. The pulsed plasma jet was created by an electrothermal plasma gun, a device that relies upon explosive vaporization of solid metal to produce a metal vapor plasma. The tests were conducted using an aluminum plasma with a pulse duration of 1 ms and a peak energy of 100 kJ on one gram specimens of PETN explosive. The specimens were placed inside a containment chamber at stand-off distances of 15 to 30 cm from the muzzle of the electrothermal gun. The effectiveness of the plasma impingement was determined by comparing post detonation experiments on the exposed and unexposed explosive

specimens. High-speed imaging of the plasma jet impinging on the explosive and post-mortum examination of the explosive specimens suggest that three distinct interactions occur. These interactions are: slow thermal decomposition (burning); rapid thermal decomposition (deflagration); and change in chemistry with negligible or no thermal decomposition. Initial results suggest that these three distinct interactions are a function of the mass flow rate and energy of the plasma and the stand-off distance.

**The Near-Field Apertureless Raman Microscope: A Novel Tool for the Chemical Identification of Single Biomacromolecules, Robert E. Martinez, Assistant Professor, Physics:** There are two principal goals of this 6.1 project: (1). to develop a novel microscope which can perform optical vibrational spectroscopy with nanometer spatial resolution, thereby offering the possibility to image *and identify chemically* individual organic molecules under study, and (2) to apply this instrument to the study of bioagents such as cytoskeletal toxins. We have completed the design and construction of our near-field apertureless Raman (NFAR) microscope. The microscope functions by placing a sharp metal needle (<20nm radius of curvature) in close proximity to the sample under study. Optical and electronic interactions with the needle cause enormous local increases in the Raman scattering cross-section of the sample. The PI's group has successfully tested the non-contact Atomic Force Microscope (AFM) operation of the NFAR, (with simultaneous optical imaging) and phase sensitive multichannel detection, which will be critical for the ultimate in spatial resolution with the NFAR instrument. Very recently we obtained evidence of  $\sim 10^6$  enhancement in Raman cross-section when the AFM tip was in proximity to a set of test samples (polystyrene film on glass; polydiacetylene 4BCMU on glass). Further work is underway to improve the quality of the metal films on the AFM tip, and to control the tip-sample interactions, to allow simultaneous topographic imaging and chemical identification using the NFAR microscope. We expect to study biopolymers and their interactions by Fall 1999.

## PUBLICATIONS

L.T. Nieman, MA Thesis, University of Texas at Austin, 1999 (in preparation) "Near-Field Apertureless Raman Microscope," to be submitted to Reviews of Scientific Instruments (in preparation)

**High School Apprenticeship Program, Dr. Gary Wilson and Ms. Elaine Frazer:** The purpose of the apprenticeship program is to provide outstanding recent high school graduates with hands-on experience in a research environment and encourage them to pursue careers in the science and engineering disciplines, particularly in those areas related to the needs of the Department of Defense. Student were selected on the basis of academic records, scholastic aptitude test results, and applications. Students were assigned to a research project under the supervision of a research staff member at ARL:UT. At the end of the apprenticeship in mid-August, students gave poster presentations to the laboratory.